Herbage Productivity and Botanical Composition of Hill Pasture as a Function of Clipping and Site Features

David P. Belesky,* Charles M. Feldhake, and Douglas G. Boyer

ABSTRACT

Complex topography and varied soil of hill-land pastures create microsite conditions that support an array of floristic associations and herbage production patterns. This complicates management for forage and livestock production because the seasonal distribution and quantity of forage vary. Our objective was to determine herbage production and floristic composition of a hill pasture as a function of site characteristics and canopy management. An existing 3-ha hill pasture watershed was oversown with white clover (*Trifolium repens* L.) and orchardgrass (*Dactylis glomerata* L.) and fertilized with reactive phosphate (PO_4) rock (PR). Replicated plots on each of four sites were clipped once (stockpiled), twice (hay harvest), or three times (long rotation) annually. Site had a significant impact on cumulative herbage production, whereas the influence of clipping was mixed. The least (1.9 Mg ha^{-1}) amount of herbage production in a given season occurred on a northeast (NE)-facing site and the greatest (4.6 Mg ha^{-1}) in a natural drainage area (ND) traversing the pasture. Herbage production increased by about 80% with overseeding and PR, but the relative ranking of production among sites stayed the same. Botanical composition was also strongly influenced by site, with velvetgrass (*Holcus lanatus* L.) predominating in ND and red fescue (*Festuca rubra* L.) occurring primarily on the NE site. The stockpiled treatments became dominated by grasses and weeds 4 yr after treatments were imposed, regardless of site, and were similar to the least productive site (NE-facing) in the pasture. Our results suggest that application of amendments to the more productive portions of a site are likely to have greater return.

THE HIGH DEGREE of spatial variability in hill-land pasture creates a range of microsite conditions (Boyer et al., 1996; Radcliffe, 1982) that influence productivity and botanical composition of plant communities (Baker, 1976). Slope aspect, for example, determines the amount of intercepted radiation (Radcliffe, 1982) and the direction and strength of air currents (Lambert and Roberts, 1976). Exposure to solar radiation and wind results in widely varying potential evaporation (Feldhake and Boyer, 1990), which interacts with soil catena to influence transpiration, makeup of the floristic community, and herbage productivity. The influence of elevation and topographic microsite on occurrence and distribution of species and vegetation is widely acknowledged and clearly presented in an example by Ayyad and Dix (1964), but very few experiments document the effects for hill-land pasture situations in the humid eastern USA.

Slope position and aspect were the most important factors influencing the distribution of prairie species in complex terrain in central Canada (Lieffers and Larkin-Lieffers, 1987). Slope aspect also influenced diversity of naturalized flora occurring at the site. Henderlong et al. (1976) noted that the seasonal distribution of Kentucky bluegrass (*Poa pratensis* L.) herbage was affected by slope aspect. The distribution pattern was a function of plant response to growing conditions interacting with the microsite conditions created by topography. Productivity was also influenced by N application, and response varied with slope aspect. Bluegrass yield was more than twofold greater on north-facing compared with south-facing slopes in northern West Virginia (Bennett et al., 1976).

Deschenes (1966) found that aspect and slope influence behavior of grazing livestock and concluded that microsite factors influencing temperature and soil water, competitive interactions among species, and the influence of grazing on plant competition and distribution of nutrients determined the species present. Topography influenced grazing duration at a given site, where duration decreased as slope steepness increased, and was least on steep slopes with southern relative to northern exposures. Aspect also influences when grazing begins, with north-facing slopes lagging behind south-facing slopes in central Appalachia (Stevens et al., 1976).

Legumes in hill pasture increase N in the sward and improve forage quality (Newbould, 1976). Bryan et al. (1987) observed that legume canopy cover, but not necessarily legume mass, was increased with P. Bryan et al. (1987) also noted that grazing management had a greater influence on sward composition than lime or P. Consequently, more intensive management approaches are desirable, such as managed grazing combined with practices that have long-lasting effects, including application of P and lime and N fixation from perennial legumes (Gillingham et al., 1998). However, evidence shows that these practices are not uniformly successful in hill-land situations (Lambert et al., 1983, 1986). Steep terrain and economic constraints might restrict precision application of soil amendments and seed mixtures. Microsite conditions including biophysical and floristic attributes could also influence renovation success. Our objective was to determine sward productivity and botanical composition as a function of clipping frequency on different sites in a seminatural hill pasture receiving a uniform application of phosphate rock (PR) and overseeding of

USDA-ARS, Appalachian Farming Syst. Res. Cent., 1224 Airport Rd., Beaver, WV 25813. Received 18 Dec. 2000. *Corresponding author (dbelesky@afsrc.ars.usda.gov).

Published in Agron. J. 94:351–358 (2002).

Abbreviations: ND, natural drainage area; NE, northeast; NW, northwest; PR, phosphate rock; SW, southwest.

orchardgrass and white clover. This work is part of a comprehensive description of the hydrologic, microclimatologic, and edaphic features of hill-land pasture.

MATERIALS AND METHODS

Site Characteristics and Plot Layout

The experiment site was a 3-ha, 210° amphitheater–shaped watershed near Cool Ridge (37°38′ N, 81°03′ W; 910 m above sea level) in southern West Virginia. The watershed was partitioned, a priori, into zones representing southwest (SW)-, northwest (NW)-, and northeast (NE)-facing aspects as well as a natural drainage area (ND) traversing the watershed and flowing to the NW (Fig. 1). Slopes ranged from 3 to 60% across the site on a Gilpin silt loam (fine-loamy, mixed, semiactive mesic, Typic Hapludult). Some characteristics of the sites are presented in Table 1, and additional details of soil and environmental characteristics, including global light and sky cover, are reported in Boyer and Feldhake (1991), Boyer et al. (1996), and Feldhake and Boyer (1990). Solar energy at the earth's surface is the sum of direct (point source) and diffuse (hemispherical) sky radiation. The total flux (direct plus sky radiation) on an unobstructed horizontal plane at the surface is global radiation. In regions of complex topography, a myriad of radiation climates created by the exposures of individual terrain facets and by shading, which reduces the effective daylength, affect direct radiation. Polar stereographic images were used to determine amount of sky covered from view by terrain and vegetation obstructions at each site. Inputs of slope steepness and aspect and vertical angle to the horizon were used in standard equations to determine daylength and potential direct radiation.

Before 1991, herbage on the site was clipped to control rank growth once or twice a year and was not managed for any agricultural production goals. Reactive (North Carolina) PR was applied by aircraft to the entire area at 2 Mg ha^{-1} in September 1991. White clover and orchardgrass were broadcast frost-seeded by hand in March 1992 at 5 and 10 kg ha^{-1}, respectively. Sheep (*Ovis* sp.)—including ewes, lambs, and wethers—mob-grazed the area at intervals throughout the course of the experiment to control herbage accumulation. Accumulated herbage was mob-grazed to a 7.5- to 15-cm residue three times during the growing season for 14- to 21-d grazing intervals. Plots used for herbage production and botanical composition measurements in the experiment were clipped, not grazed (sheep were excluded from the plot area).

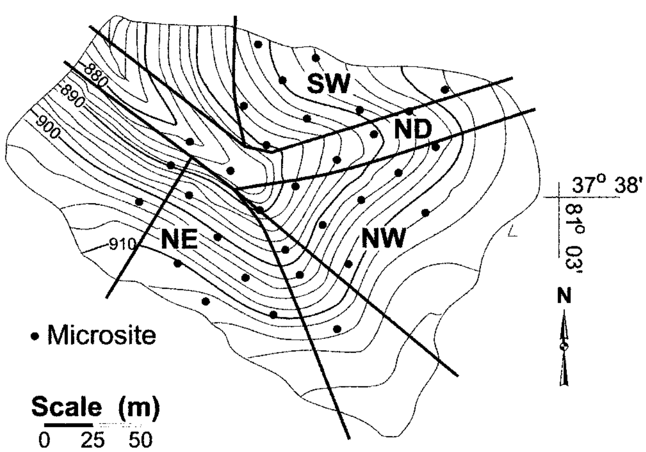

Fig. 1. Layout of research watershed showing elevation gradient, the four topographic regions (SW, southwest; ND, natural drainage; NW, northwest; and NE, northeast sites), and the microsite locations for plots within each topographic region used to determine herbage production and botanical composition.

Table 1. Means and standard errors for slope, global light, and sky cover for each site (SW, southwest facing; ND, natural drainage; NW, northwest facing; and NE, northeast facing) in a steep hill-pasture watershed. Data are adapted from Boyer and Feldhake (1987).

Site	Slope	Global light†	Sky cover‡
		%	
SW	30 ± 4	33 ± 3	34 ± 3
ND	14 ± 5	49 ± 6	43 ± 5
NW	32 ± 3	37 ± 2	49 ± 6
NE	48 ± 4	39 ± 2	53 ± 1

† Global light presents the hemispherical view and seasonal variation in incident and diffuse light as a function of sun path. Values are the mean of four locations on each site.

‡ Sky cover represents the fraction of sky covered by solid horizon or obstructions such as trees or structures. Values presented are a mean for each of four locations on each site.

Treatments and Sampling

Four replicate plots (2 by 3 m) of each clipping regime were situated near microclimate monitoring stations in each of the four sites for a total of 16 plots (Fig. 1). Details of location of the microclimate monitoring stations and some characteristics of the watershed are presented in Feldhake and Boyer (1990). Herbage was clipped from the center of each plot to a 5-cm residue from 0.6- by 2-m strips with a collection bag–equipped rotary mower beginning in May (on or about Calendar Day 130). Canopy management treatments included long rotation clipped three times (mid-May, late July, and late September), hay clipped twice (late July and again in late September), or stockpiled and clipped in late September. The final clip for each treatment was made at the end of the growing season when the stockpiled treatment was harvested. Clipping began in spring of 1991, before application of PR and overseeding, and continued for 4 yr (1992–1995) from the time of application. We omitted data from 1992 in the analysis and summary because we considered it an establishment year.

Botanical composition was determined in mid-May, late July, and late September each year by the two-dimensional point-intercept method described by Warren-Wilson (1959) and by line intersect. The two-dimensional assessment was a 1-m^2 area with a grid of 81 contacts, and the line-intersect method was represented by two 1-m-long transects in each plot, with species identified at 10-cm interval contacts. Values from the two procedures were meaned. Contacts were categorized as orchardgrass, tall fescue (*F. arundinacea* Schreb.), red fescue, velvetgrass, red clover (*T. pratense* L.), white clover, or other taxa (frequent representation by species of *Plantago*, *Potentilla*, *Vernonia*, *Heiracium*, *Andropogon*, *Danthonia*, *Fragaria*, *Ambrosia*, and *Taraxacum*) bare ground or dead (senesced) herbage.

Data for annual cumulative yield and botanical composition were analyzed as a split-plot design using SAS-MIXED procedure (Littell et al., 1996). Site and canopy management were fixed effects and replication random in the model. Years were analyzed separately within the mixed model because chi-squared test for cumulative yield and botanical composition indicated heterogeneity of variance. Cumulative yield data were balanced, so the default degrees of freedom were used to obtain the error terms. Botanical composition data sets were unbalanced; consequently, the split-plot error terms differ for each year. Denominator degrees of freedom were calculated using the Satterthwaite option of MIXED analysis to determine the appropriate degrees of freedom. Single degree-of-

Table 2. Significance of the effects of site, canopy management, the interaction of site × canopy management, slope, global light, sky cover, and harvest time on cumulative herbage yield.

	1991	1993	1994	1995
Site (S)	**	***	***	***
Canopy management (CM)	***	***	*	NS†
S × CM	***	**	NS	**
Slope	NS	NS	NS	NS
Global light	NS	NS	NS	NS
Sky cover	**	*	NS	NS
Harvest date	***	***	***	***

* Significant at $P < 0.05$.
** Significant at $P < 0.01$.
*** Significant at $P < 0.001$.
† NS, not significant.

freedom contrasts were used to compare main-effect means. The SLICE option of the MIXED procedure enabled us to determine which simple effect of an interaction—in this case, the interaction of site and canopy management—had the most influence on that interaction. Pearson correlation coefficients were calculated to determine the relationship of orchardgrass or white clover with other botanical components of the sward, senesced leaf and bare ground (devoid of vegetation). Botanical composition data were transformed (square root + 0.5) to determine the influence of years. Data presented are the original values.

Correlation coefficients were generated for cumulative yield and botanical composition and microsite attributes using the PROC CORR procedure of SAS. A multiple linear regression model was fit to the cumulative yield and botanical data using the independent variables of site, canopy management, global light, sky cover, slope, and harvest date. The STB option in the model was used to generate standardized regression coefficients. The advantage of standardized regression coefficients is that magnitude shows the relative strengths of the effects of several independent variables on the same dependent variable, which in this case, was cumulative herbage mass or the contribution of a particular botanical component. This procedure eliminates the effect of differences in measurement scale for different independent variables. Data were tested for multicollinearity using the COLLINOINT option for multiple linear regression models, which adjusts for the intercept, makes all independent variables orthogonal to the intercept, and removes any collinearity involving the intercept.

RESULTS AND DISCUSSION

Cumulative Yield

Site had a highly significant and consistent influence on cumulative yield (Table 2). Other attributes associated with topography, such as slope and the amount of incident light and interdicting terrain features expressed as sky cover, had less influence on cumulative yield. Aspect is part of a composite of terrain features—including slope, soil depth, orientation to sun path, and resulting microclimate characteristics—that influences the floristic composition and productivity of a given site. We fit a multiple linear regression model for cumulative yield based on aspect, slope, global light, and sky cover. An eigenvector matrix, generated to resolve the collinearity of attributes on cumulative yield, showed that site accounted for 92% of the variance, with moderate

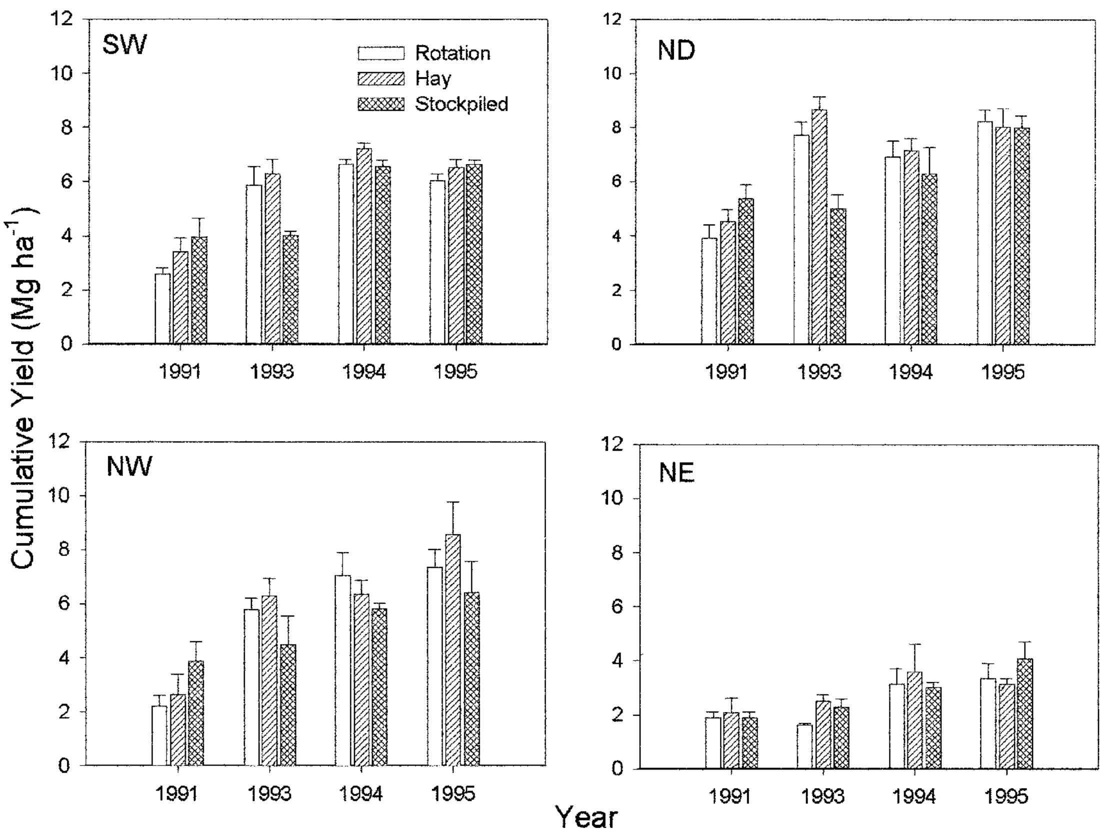

Fig. 2. Yearly cumulative yield (Mg ha^{-1}) of hill-land pasture treated with phosphate rock (PR) and overseeded with white clover as influenced by site (SW, southwest; ND, natural drainage; NW, northwest; and NE, northeast) and canopy management. Vertical bars are standard error of the mean.

Table 3. Significance of single degree-of-freedom contrasts for the influence of site (SW, southwest facing; ND, natural drainage; NW, northwest facing; and NE, northeast facing) on cumulative herbage yield.

Comparison	1991	1993	1994	1995
SW vs. ND	NS†	*	NS	*
SW vs. NW	NS	NS	NS	NS
SW vs. NE	*	***	***	***
ND vs. NW	*	*	NS	NS
ND vs. NE	***	***	***	***
NW vs. NE	NS	***	***	***

* Significant at $P < 0.05$.
*** Significant at $P < 0.001$.
† NS, not significant.

Table 4. Significance of the simple effects of the interaction of site × canopy management† on cumulative herbage yield.

	$P > F$			
	1991	1993	1994	1995
Influence of site within each canopy management†				
Rotation	NS‡	<0.0001	<0.0001	<0.0001
Hay	0.02	<0.0001	<0.0001	<0.0001
Stockpiled	<0.0001	0.003	<0.0001	<0.0001
Influence of canopy management within each site§				
SW	NS	<0.0001	NS	NS
ND	<0.0001	<0.0001	NS	NS
NW	0.0002	0.002	0.03	0.0003
NE	0.0005	NS	NS	NS

‡ SW, southwest facing; ND, natural drainage; NW, northwest facing; and NE, northeast facing.
‡ NS, not significant.
§ Rotation, clipped three times; hay, clipped twice; stockpiled, clipped once.

influence from slope (47%), sky cover (61%), and global light (54%).

Cumulative yield differed among aspects with yields from the NE-facing site least and from ND the greatest (Fig. 2). The difference in cumulative herbage yield for NE and ND remained distinct throughout the experiment (Table 3). Cumulative yield was greatest from the ND probably because of adequate moisture occurring in the low-lying area throughout the growing season as well as other microsite-related conditions. Yields in the ND were from 1.5 to 2 times greater than comparably managed canopies on the other sites in the first year of the experiment. The lowest yields occurred on the NE-facing site, which had the greatest slope, the least incident light (Boyer and Feldhake, 1991), and the shallowest soil (Boyer et al., 1996) among the sites. Yields increased at different rates during the growing season, depending on site, during the course of the experiment. When comparing 1991 to 1995, cumulative yields for the NE-facing site increased by 71%, and those on the NW site increased by 162%. Yields on the NE site were about 60% of those obtained on other sites in 1991 and dropped to about 47% of maximum yields obtained on the other sites in 1995, suggesting that overseeding and PR application was somewhat more effective on sites other than those facing NE.

Site interacted with canopy management to influence cumulative yield (Table 4). The influence of canopy management within a site was mixed in terms of cumulative yield and seemed to have less influence as the experiment progressed. In contrast, when site was considered within a particular management, then influence on cumulative yield was highly significant. Cumulative yields for SW, NW, and ND sites differed with canopy management, whereas cumulative yields on NE site, regardless of canopy management, were similar each year. For example, stockpiling herbage tended to depress cumulative yield relative to other treatments on SW, NW, and ND sites in 1993 and 1994 (Fig. 2). By 1995, cumulative yields were comparable among canopy management on all sites except that facing NW. Average yield across sites and canopy management in 1995 (6.4 Mg ha^{-1}) was double that (3.2 Mg ha^{-1}) obtained for 1991 (before overseeding and PR application).

Stockpiled herbage mass (averaged over years) was less than that obtained from the rotation or hay canopies on more productive sites such as ND or SW, probably because of leaf senescence and self shading that reduced the appearance of replacement tillers. Yields from rotation swards in our experiment were comparable to those obtained from paddocks grazed three or four times annually as reported by Bryan et al. (1987). Differences could be a combined result of growing conditions associated with site and botanical composition of the sward. Results suggest that conditions on the NE-facing site are such that overseeding and PR alone may not improve herbage production.

Botanical Composition

Botanical composition of the sward differed among years (Fig. 3). For example, both red and white clover increased dramatically in 1993 after overseeding and grazing but dropped to pre-1993 levels later in the study. Some differences in botanical composition occurred as a function of canopy management, but these were overshadowed by the large and highly significant influence of site. Eigenvector matrix data showed that site accounted for 74% of the variance for botanical components in each year and that slope had a slightly stronger influence on components in 1991 (77% of the variance) than in subsequent years (71%). Other factors, including global light, sky cover, and canopy management, had minimal influence on botanical composition. The tendency was for stockpiled canopies to be mostly grass and weeds with little clover (Fig. 3). The presence of clovers was greatest in the rotational canopy management. The proportion of grasses in the sward increased, in general, during the course of the experiment on NE and ND sites and varied with years on the SW and NW sites (Fig. 3). Despite overseeding with orchardgrass, the proportion of all grasses in the sward did not always increase relative to grasses present in 1991. The relative amounts of individual grass species changed with year (Fig. 4).

Grass

Grasses represented a greater proportion of herbage than did other sward components on the NE site and ranged from about 45 to 75% of the total herbage. The proportion of grass in the sward on the NE site increased

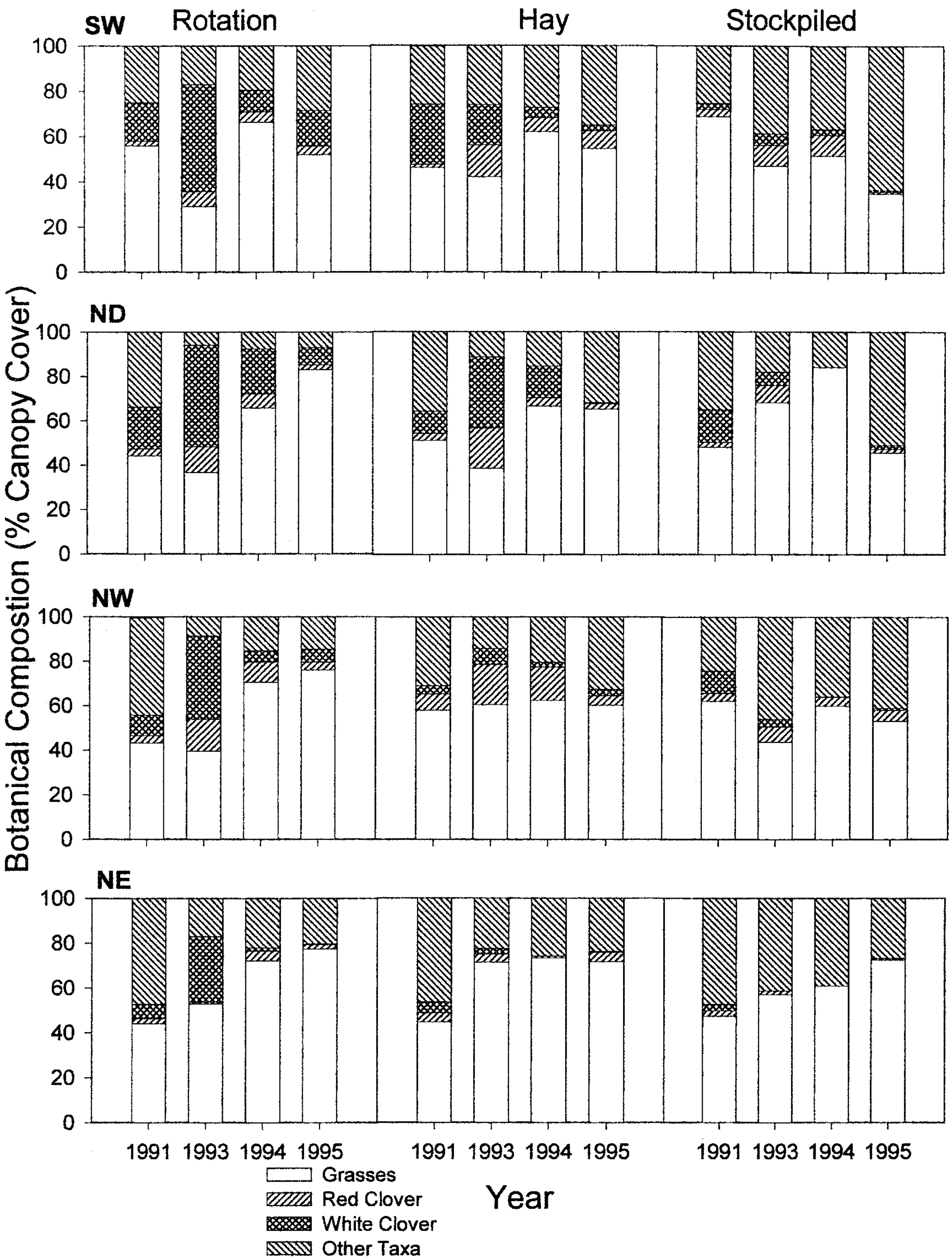

Fig. 3. Botanical composition of swards as a function of site (SW, southwest; ND, natural drainage; NW, northwest; and NE, northeast) and canopy management.

as a proportion of the total herbage from 1991 through 1995, regardless of canopy management. Grasses on other sites ranged from a low of 30% on the SW site to more than 80% of the sward in ND at certain times and under particular canopy treatments.

While each grass species identified in the pasture occurred on each site, certain species predominated on a particular site. Orchardgrass dominated the grass component of swards on the NW and SW sites by 1993 (Fig. 4). The increase in orchardgrass occurred as red fescue declined, regardless of year (1991, $r_{n=128} = -0.55$, $P < 0.001$; 1993, $r_{n=128} = -0.35$, $P < 0.001$; 1994, $r_{n=128} = -0.40$, $P < 0.001$; 1995, $r_{n=128} = -0.25$, $P < 0.01$). Red fescue dominated the grass component of the sward on the NE site, where cumulative yield was the least, throughout the experiment (Fig. 4). Velvetgrass as a

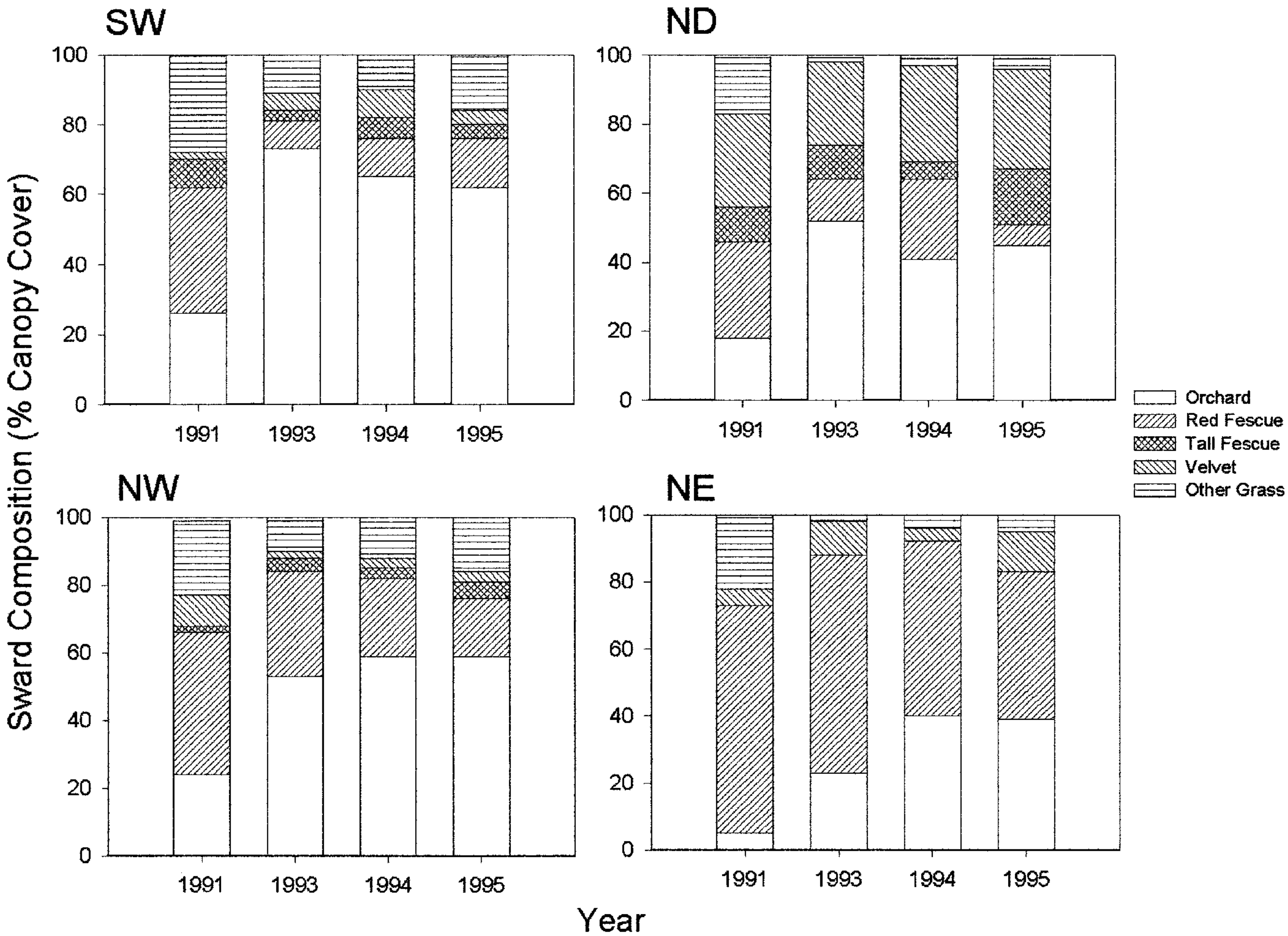

Fig. 4. Relative contribution of individual grass species to the grass component of the swards as a function of site (SW, southwest; ND, natural drainage; NW, northwest; and NE, northeast).

fraction of the grass component was greatest in the ND, where cumulative yield was consistently high, and least on the NW site (Fig. 4). The relative amount of velvetgrass changed very little within a given site across years. Simple correlation of slope (%) with specific grasses showed a significant ($P < 0.01$) positive correlation ($r > 0.4$) of red fescue with slope during the course of the experiment. Weak negative correlations with slope occurred at times for orchardgrass, tall fescue, velvetgrass, and the other grass components at the site (data not shown).

The influence of canopy management on the grass component of the sward was inconsistent. Applying PR and overseeding increased the proportion of orchardgrass and decreased red fescue in the grass component (Fig. 4) but did not always increase the relative amount of grass as a fraction of total botanical composition of the sward (Fig. 3). Irrespective of abundance, velvetgrass and red fescue are less likely to respond to soil nutrient inputs than improved grasses such as orchardgrass and tall fescue (Frame, 1991). Reseeding pastures to improved species may not always be justified where inputs, especially N, remain low and site conditions, such as competition from indigenous species, present additional challenges to renovation. While naturalized grasses can make a substantial contribution to total herbage production, their lesser nutritive value or acceptability by grazers, as is the case for red fescue, could limit livestock productivity (Frame, 1991).

White and Red Clover

Clover was present in the pasture before overseeding and PR application (1991) and ranged from about 10 to 20% of the botanical composition of the sward (Fig. 3). Clover was greatest in 1993 and 1994, the years following overseeding, especially when canopies were clipped frequently or managed as hay. Clover flourished after application of P and grazing. Stockpiling herbage depressed clover yield relative to the other canopy managements after overseeding and PR application and appeared to accelerate the demise of clovers with time relative to pretreatment sward composition. Clover was least on the NE site and greatest on the SW site during the experiment. Our data agree with Gillingham et al. (1998) regarding increased frequency of white clover on gentle slopes compared with steep (represented by the NE site in our experiment) slopes. Clover ranged from 55% of the cover in the sward in 1993 on the NW, SW, and ND sites under the rotation treatment to none at all in stockpiled canopies by 1994 in the ND and the NE sites. Clover in hay was intermediate relative to rotational and stockpiled canopy treatments, irrespective of site. The proportion of white clover in the sward was inversely associated with the proportion of orchardgrass (1991, not significant; 1993, $r_{n=128} = -0.32$, $P < 0.01$; 1994, $r_{n=128} = -0.20$, $P < 0.05$; 1995, $r_{n=128} = -0.20$, $P < 0.05$) and other taxa (1991, $r_{n=128} = -0.43$, $P < 0.001$; 1993, $r_{n=128} = -0.46$, $P < 0.001$; 1994, $r_{n=128} = -0.34$, $P < 0.001$; $r_{n=128} = -0.40$, $P < 0.001$; 1995, not significant).

Other Taxa

The proportion of other taxa tended to be greatest in stockpiled compared with other canopy management regimes (Fig. 3). Some of the weedy species included in the other taxa category were tall-growing forbs such as *Ambrosia* spp. and *Vernonia* spp. that require undisturbed canopy conditions to flourish. Increases in other species could be associated with prolonged dry intervals in autumn of 1994 and again in spring and midsummer of 1995. We did not quantify individual forbs but simply grouped them into the *other taxa* category, so we are unable to present changes in weed species occurrence as a function of year, site, and canopy management. The contribution of other taxa to sward cover was less after overseeding and PR application in the rotational canopy management on all sites and on the ND, NW, and NE sites when managed as hay. The production of other taxa on the SW site did not seem to be influenced by the combination of overseeding and PR application.

Our results agree with those of Bryan et al. (1987) and earlier observations made by Suckling (1976) that canopy management is an important influence on botanical composition of hill pasture. Simple practices such as overseeding and PR application had substantial influence on sward productivity and botanical composition regardless of slope site. Gillingham et al. (1998) noted that gently sloping sites in a pasture were more likely to have greater production than more steeply sloped sites because of soil moisture gradients. Neighbor effects (Thompson and Harper, 1988) also influence competition within the sward as a function of light quality. Successful establishment and floristic composition is not limited to the conditions existing at the time but may be a function of pre-existing plant community structure, its influence on soil microbial community, and interactions between components (Mathews and Clay, 2001).

In our experiment, site had a greater influence than clipping on production and botanical composition of the sward. Red fescue was the dominant species on the NE-facing slope under conditions of relatively greater slope, lower light, and shallow soil, and velvetgrass flourished in the sheltered, relatively moist natural drainage zone at the lowest points in the pasture. We did not expect increased production from these species when PR was applied or when legume improved the N status of the site. Management practices inconsistent with the needs of species, including orchardgrass and white clover, seem to accelerate floristic change. More intensive management practices appear to be needed to disturb accumulated plant residue and the soil surface when renovating hill-land pasture areas that were previously under long-term extensive management. Our results support observations made by Lambert and Roberts (1976) and recently by Gillingham et al. (1998) that application of amendments to the more productive portions of a pasture are likely to have greater return.

ACKNOWLEDGMENTS

We thank J.M. Ruckle, J.M. Fedders, G.D. Lambert and R.C. Arnold for excellent technical assistance. We also appreciate the help provided by many others involved in this project from inception in 1984 until completion in 1995. Thanks also to Prof. W.B. Bryan for review of initial drafts of the manuscript and to E.B. Rayburn, M.J. Williams, and M.A. Sanderson for insightful and thorough review of the text.

REFERENCES

Ayyad, M.A.G., and R.L. Dix. 1964. An analysis of vegetation micro-environmental complex on prairie slopes in Saskatchewan. Ecol. Monogr. 34:421–442.

Baker, B.S. 1976. Production and species composition of hill pasture as influenced by lime and fertilizer. p. 171–175. *In* J. Luchok et al. (ed.) Hill lands. Proc. Int. Symp., Morgantown, WV. 3–9 Oct. 1976. WVU Books, Morgantown, WV.

Bennett, O.L., E.L. Mathias, and G.A. Jung. 1976. Responses of perennial grasses and legumes to slope and microclimate. p. 476–491. *In* J. Luchok et al. (ed.) Hill lands. Proc. Int. Symp., Morgantown, WV. 3–9 Oct. 1976. WVU Books, Morgantown, WV.

Boyer, D.G., and C.M. Feldhake. 1987. An optographic analysis of terrain effects on the thermal climate of a steep pasture. p. 31–34. *In* Conf. on Biometeorol. and Aerobiol., 18th, Lafayette, IN. 14–18 Sept. 1987. Preprint volume. Am. Meteorol. Soc., Boston, MA.

Boyer, D.G., and C.M. Feldhake. 1991. Distribution of horizon-limited direct beam potential radiation in steep pastures. Earth Surf. Processes Landforms 16:1–10.

Boyer, D.G., R.J. Wright, C.M. Feldhake, and D.P. Bligh. 1996. Soil spatial variability in a steeply sloping environment. Soil Sci. 161: 278–287.

Deschenes, J.-M. 1966. Vegetation differences of north and south slopes of grazed pastures of Sussex County, New Jersey. Bull. N.J. Acad. Sci. 11:22–29.

Feldhake, C.M., and D.G. Boyer. 1990. Bellani evaporation variation in hill-land pasture. Agric. For. Meteorol. 51:211–222.

Frame, J. 1991. Herbage productivity and quality of a range of secondary grass species at five rates of fertilizer nitrogen application. Grass Forage Sci. 46:139–151.

Gillingham, A.G., M.H. Gray, and D.R. Smith. 1998. Pasture response to phosphorus and nitrogen fertilizers on dry hill country. Proc. N.Z. Grassl. Assoc. 60:135–140.

Henderlong, P.R., O.L. Bennett, and E.L. Mathias. 1976. Seasonal yield distribution, N fertilizer response and utilization of *Poa pratensis* on north- and south-facing slopes. p. 592–596. *In* J. Luchok et al. (ed.) Hill lands. Proc. Int. Symp., Morgantown, WV. 3–9 Oct. 1976. WVU Books, Morgantown, WV.

Lambert, M.G., D.A. Clark, D.A. Grant, D.A. Costall, and Y.S. Gray. 1986. Influence of fertilizer and grazing management on North Island moist hill country: IV. Pasture species abundance. N.Z. J. Agric. Res. 29:23–31.

Lambert, M.G., D.A. Clark, D.A. Grant, D.A. Costall, and R.H. Fletcher. 1983. Influence of fertilizer and grazing management on North Island moist hill country: I. Herbage accumulation. N.Z. J. Agric. Res. 26:95–108.

Lambert, M.G., and E. Roberts. 1976. Aspect differences in an unimproved hill country pasture. N.Z. J. Agric. Res. 19:459–467.

Lieffers, V.J., and P.A. Larkin-Lieffers. 1987. Slope, aspect and slope position as factors controlling grassland communities in the coulees of the Oldman River, Alberta. Can. J. Bot. 65:1371–1378.

Littell, R.C., G.A. Milliken, W.W. Stroup, and R.D. Wolfinger. 1996. SAS systems for mixed models. SAS Inst., Cary, NC.
Mathews, J.W., and K. Clay. 2001. Influence of fungal endophyte infection on plant–soil feedback and community interactions. Ecology 82:500–509.
Newbould, P. 1976. Techniques for hill land improvement used in the United Kingdom. p. 66–77. *In* J. Luchok et al. (ed.) Hill lands. Proc. Int. Symp., Morgantown, WV. 3–9 Oct. 1976. WVU Books, Morgantown.
Radcliffe, J.E. 1982. Effect of aspect and topography on pasture production in hill country. N.Z. J. Agric. Res. 25:486–496.
Stevens, L.P., G.C. Anderson, and P.R. Henderlong. 1976. Ecological and production aspects of a north and south facing slope pasture system. p. 587–591. *In* J. Luchok et al. (ed.) Hill lands. Proc. Int. Symp., Morgantown, WV. 3–9 Oct. 1976. WVU Books, Morgantown, WV.
Suckling, F.E.T. 1976. A 20-year study of pasture development through phosphate and legume oversowing on North Island hill country of New Zealand. p. 367–381. *In* J. Luchok et al. (ed.) Hill lands. Proc. Int. Symp., Morgantown, WV. 3–9 Oct. 1976. WVU Books, Morgantown.
Thompson, L., and J.L. Harper. 1988. The effect of grasses on the quality of transmitted radiation and its influence on the growth of white clover *Trifolium repens*. Oecologia (Berlin) 75:343–347.
Warren-Wilson, J. 1959. Analysis of spatial distribution of foliage by two-dimensional point quadrat. New Phytol. 58:92–101.

TURFGRASS MANAGEMENT

Effect of Profile Layering, Root Zone Texture, and Slope on Putting-Green Drainage Rates

Guy W. Prettyman and Edward L. McCoy*

ABSTRACT

A gravel layer underlying the root zone in a United States Golf Association (USGA) putting green and a typically higher root zone permeability in a University of California green should yield water drainage differences between these construction methods. This study examined effects of soil profile layering, root zone permeability, and slope on water drainage from experimental putting greens. The study employed either one-tier or two-tier putting green soil profiles, with each containing root zones having either 530 or 320 mm h^{-1} water permeabilities. The 1.2- by 7.3-m greens were adjusted to slopes of 0, 2, and 4%, and simulated rain was applied at either 45 or 112 mm h^{-1}. Drainage outflow from the furthest down-slope drain line was monitored during rainfall and for 48 h after rain stopped. During rain, the two-tier greens had greater drainage rates, and drainage in these greens did not depend on root zone permeability. In the early drainage period (from 1 to 9 h after rain stopped), profile design and root zone permeability interacted such that the largest drainage rate was from the one-tier, higher-permeability green and the smallest drainage rate was from the one-tier, lower-permeability green. Later in the drainage period (from 27 to 45 h), increased green slope contributed higher drainage rates for all experimental greens. This research illustrates that both profile design and root zone permeability contribute to the drainage process in putting greens with high sand content.

SAND-DOMINATED SOIL TEXTURES are the preferred medium for the root zone of a golf putting green. These root zones provide superior playing conditions while generally meeting the agronomic demands of the turf. The overlying factor dictating the use of root zones with high sand content is that hydraulic conductivity is not severely reduced by compaction (Adams et al., 1971). Further, high-sand greens provide a true and consistent putting surface that can hold a lofted golf shot under a wide range of soil moistures (Lodge, 1992). To aid the performance of sand-dominated root zones, modern putting greens also employ some form of soil profile design including a subsurface drainage system.

Currently, the two most common soil profile designs of putting greens are the University of California (Davis et al., 1990) and the United States Golf Association (USGA) (USGA Green Section Staff, 1993) putting-green construction techniques. Both green designs are built on a compacted subgrade consisting of soil native to the site, and both contain a closely spaced array of subsurface drainpipes placed in gravel-filled trenches cut into the subgrade. Both also contain a 0.3-m root zone depth. The principal soil profile difference in these construction methods is the presence of a gravel layer (≈0.1-m thick) underlying the root zone in a USGA green. Thus, a USGA profile containing a gravel layer underlying the root zone is commonly referred to as a two-tier design. A University of California profile may be referred to as a one-tier design due to the absence of the gravel layer. Another major difference in these construction methods is a typically higher saturated hydraulic conductivity of the root zone in a California green.

Subsurface drainage of putting-green root zones has both intensity and capacity attributes. Intensity of subsurface drainage is the rate of water removal and delivery to the drains. Capacity of drainage, on the other hand, is the volume of water removed after root zone drainage rates become small. With regard to the intensity of subsurface drainage, the hydraulic gradient along the streamlines and the root zone hydraulic conductivity both contribute to drainage rate. The USGA and California profile designs conceptually (van Schilfgaarde et al., 1957) should yield distinctly different hydraulic

School of Nat. Resour., Ohio State Univ., Ohio Agric. Res. and Dev. Cent., 1680 Madison Ave., Wooster, OH 44691. Received 8 Aug. 2000. *Corresponding author (mccoy.13@osu.edu).

Published in Agron. J. 94:358–364 (2002).

Abbreviations: MS, mean square; USGA, United States Golf Association.